

MAXIMAL AEROBIC POWER MEASUREMENT IN RUNNERS AND SWIMMERS

I. CORRY, BSc* and N. POWERS, MA, BChir, PhD

Department of Physiology, University of Edinburgh

ABSTRACT

Five cross-country runners and five competitive swimmers performed a pulling exercise with elastic shock cords and a treadmill run to exhaustion. The mean VO_2 max related to lean body mass of the runners was significantly higher than the swimmers on the treadmill ($p < 0.05$) while, on the pulling test, the mean VO_2 max of the swimmers was significantly higher than the runners ($p < 0.01$).

The maximum heart rates achieved pulling were 95% of the running maximum by runners and 96% by swimmers with no significant difference between them. Their mean oxygen pulse was almost the same for maximal running but the swimmers had a significantly higher oxygen pulse than the runners for maximal pulling ($p < 0.01$). The swimmers could reach about 79% of their running VO_2 max by pulling while the runners used 53% of their running VO_2 max.

Key words: Maximum oxygen uptake, Swimmers, Runners, Arm ergometry, Treadmill running.

INTRODUCTION

Maximal aerobic power (MAP) which is expressed as VO_2 max (Hermansen, 1973) is the best laboratory measurement of an individual's capacity for prolonged heavy work (Åstrand and Rodahl, 1977; Harrison et al, 1980; Robinson, 1980) since there is a strong positive correlation between VO_2 max and physical work capacity (De Vries, 1977; Taylor et al, 1962). As an estimate of fitness it ignores strength, agility, motivation and technique, but it is indicative of the functional state of the respiratory, circulatory and metabolic systems (Hermansen, 1977; Nagle, 1973).

In evaluation of MAP in athletes it becomes important to select a work situation which allows optimal use of specifically trained muscle fibres (Stromme et al, 1977). So, instead of using a generalised "whole body" VO_2 max, the VO_2 max for a specified exercise may be a more useful measurement in estimation of a specifically trained athlete's performance potential, even if it is a lower value than the VO_2 max measured using a larger muscle mass but including muscles not so highly trained.

A swimmer is a good example of a specifically trained athlete whose VO_2 max during swimming is difficult to measure, while VO_2 max for treadmill running or cycling includes the use of muscles untrained in those activities. That intensive swim training need not be linked to any increase in VO_2 max running has been suggested (Holmer, 1974; McArdle et al, 1978; Magel et al, 1975) nor is running an effective modality to enhance MAP for swimming (McArdle et al, 1978).

A form of land ergometry using the swimming style

pulling exercise is sure to involve swimmers' muscles in a similar role to in the water and might be useful in monitoring the changes in a swimmer's aerobic power during the course of a training programme. The widely documented arm cranking (e.g. Vokac et al, 1975) is an activity unrelated to swimming but we suggest that pulling as performed in this study utilises the prime movers of the swimmers upper body. We have seen only one other study using swimming-style pulling technique, but the pulling movement was not standardised — "each swimmer simulated his principal competitive stroke" — and no comparison was made with other sportsmen or non-athletes (Armstrong and Davies, 1981).

In this study, the aerobic power of swimmers and runners is compared by tests related to their respective disciplines, running for the runners and pulling for the swimmers. By these tests their specific adaptations can be shown and the usefulness of the pulling test for swimmers may be established.

Having shown the adaptation of swimmers to this test, confirming our views, the next stage would be to examine the aerobic power of swimmers swimming and correlate this with their VO_2 performance pulling; this has not yet been done.

SUBJECTS

Five cross-country runners, and five competitive swimmers, three men and two women in each group (see Table I), were invited to participate in two types of ergometry, to investigate the specificity of their aerobic power to running or pulling.

APPARATUS

Running was performed on a Morgan treadmill inclined at 7° , 12.2% and the speed was varied.

*Present Address:

2 Cardigan Drive,
BELFAST, BT14 6LX

TABLE I

Subject	Age	Weight		LBM $\dot{V}O_2$ max		L.min ⁻¹	Status
		kg	kg	pull	run		
Swimmers							
A	21	70.2	61.4	3.21	4.34	Scottish International Swimming and Water Polo, 100 m men's Back Crawl 1:00.5	
B	21	79.3	68.8	3.77	4.70	Scottish Universities and East District representative, 100 m men's Front Crawl 56.0	
C	15	79.2	69.0	3.87	5.36	Scottish Junior International, 100 m men's Back Crawl 1:02.0	
D	18	66.8	51.8	3.29	3.95	Scottish International 200 m women's Butterfly 2:27.3	
E	20	75.5	57.5	3.32	3.92	Scottish International 200 m women's Front Crawl 2:10.03	
mean	19	74.2	61.66	3.49	4.45		
		s.d.	s.d.	s.d.	s.d.		
		± 5.56	± 7.36	± 0.3	± 0.6		
Runners							
G	19	71.7	63.9	2.92	4.79	N. Ireland AAA Junior representative, 10th British Junior in men's 3000 m steeple-chase,	
H	18	60.5	53.4	2.49	4.55	British Junior men's orienteering champion men's	
J	20	52.2	48.0	2.30	3.54	Men's Scottish Universities and English County representative	
K	24	58.2	47.1	1.69	4.11	Women's Scottish International 1500 m, 3000 m, and cross-country	
L	20	53.0	45.0	1.69	3.75	Women's Scottish International cross-country representative	
mean	20	59.12	51.48	2.22	4.15		
		s.d.	s.d.	s.d.	s.d.		
		± 7.85	± 7.6	± 0.53	± 0.53		

Pulling was tested using elastic shock cords at the rate set by a metronome. On the inspiratory side, a pneumotachograph integrator (Mercury electronics CS5) recorded tidal volume, the air being inhaled via corrugated tubing vol. 500 cm³. The mouthpiece for pulling was a Siebe-Gorman valve while for running a perspex low resistance valve was used similar to the design of

Programme: Sample of calculation by the Hewlett-Packard

O2 CONSUMPTION RQ & ENERGY EXPENDITURE

TIME MIN. SEC?	0.20
I.E.	0.33 MIN
FINAL LITRES?	100.00
INITIAL LITRES?	60.00
	40.00
GAS TEMP?	21.00 DEG
METER CORRECTION FACTOR?	0.98
BAR P?	100.60 KPA
VAP P = 2.5 KPA	
CO2 %?	4.00
O2%	17.00
\dot{V} DOT = 105.741/LI $\leftarrow \dot{V}_e$	
O2 INHALED = 22.12 L/MIN	
O2 EXHALED = 17.98 L/MIN	
O2 CONSUMPTION = 4.14 L/MIN $\leftarrow \dot{V}O_2$	
CO2 EXHALED = 4.20 L/MIN $\leftarrow \dot{V}CO_2$	
RQ = 1.01 \leftarrow R.Q.	
POWER (WEIR) = 1430W	

OTIS and MACKERIS (Åstrand and Rodahl, 1977). Expiratory gas was collected after passing through an external dead space of 850 cm³ (pulling), 880 cm³ (running) in Douglas bags via a 3-bag changing junction.

Heart rate was calculated from three ECG leads and a pneumotachograph trace was also plotted on the same recording.

Gas analysis was performed by blowing the gas through a dry gas meter previously calibrated. Samples of dried gas from the bags were analysed for carbon dioxide and oxygen previously calibrated using standard gases and checked against the atmosphere between every sample analysis.

Using the gas reading, its correction factor, % CO₂, %O₂, barometric pressure and room temperature, the data shown on the computer print out, illustrated in Fig. 2, were calculated on a Hewlett HP 981 5A calculator. On this, the vapour pressure was calculated using an algorithm accurate in the range 8°-37° and leaving an error from this source of 0.1% in the results.

Skin folds to estimate % fat and hence LBM were taken using Harpenden skin fold calipers and compared with the Durnin and Womersley Nomogram allowing an error of ± 3.5% ♀, ± 5% ♂ (Durnin and Womersley, 1974).

The statistical analysis was by the Unpaired Students t-test, with significance assumed at p < 0.05.

ERGOMETRY

The running test was of the continuous type, the speed being increased until the subject was unable to continue; the gradient remained at 7° (Fig. 1). After a warm-up of stretching exercises and a jog on the treadmill at 6-8 kph without a mouthpiece, the subject ran at two submaximal speeds, the aims of which were 3-fold.

1. A warm-up for the subject under experimental conditions.
2. Using the heart rate achieved, the experimenter calculated speeds likely to give heart rates of 150, 170 and maximum for the first three stages of the test.
3. The subject practised stopping the treadmill by a red button in front of him or by pulling on his safety harness.

After a 10-15 min rest in an armchair the test began, protocol Fig. 2. Speed one was aimed to give a HR 150, speed two 170. Speed three, etc. were increased at the same increment until exhaustion.

The pulling was performed using elastic shock cords after a warm-up of stretching and two practice periods on the cords. The subject was standing, leaning forward and pulling from arm's length, at the point where the cords just became tense to the outside of the thigh (Fig. 3). This meant that the subject's reach determined his workload; the shock cord tension and the range for each subject are shown in Fig. 4. The rate of pulling, alternate right arm left arm, was determined by a metronome at three settings (Protocol, Fig. 5).

Exhaustion was determined by an observer when it became clear that the subject, although maintaining the correct rate, could no longer pull the handle back to his thigh.

$\dot{V}O_2$ max was the highest $\dot{V}O_2$ achieved during the course of the test, measured from expired gas collected during 20 second periods in Douglas bags. Examples of the time course for reaching $\dot{V}O_2$ max are shown graphically in Fig. 6.

In both tests, the cumbersome nature of the gas collecting apparatus and the inexperience of the athletes in performing the exercises may have introduced some individual variation related to each person's adaptation to the novel situation. This cannot be quantified.

DISCUSSION

$\dot{V}O_2$ max for arm cranking has been shown to be 68% to 78% of the $\dot{V}O_2$ max for leg work in unathletic subjects (Reybrouck et al, 1975; Vokac et al, 1975). Our results show that the runners could reach 41% to 64% of their running $\dot{V}O_2$ max in the pulling exercise;

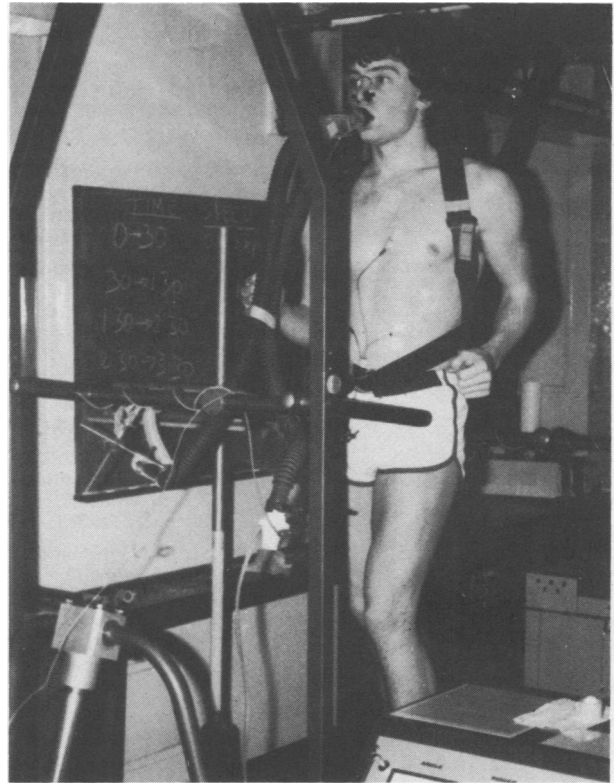


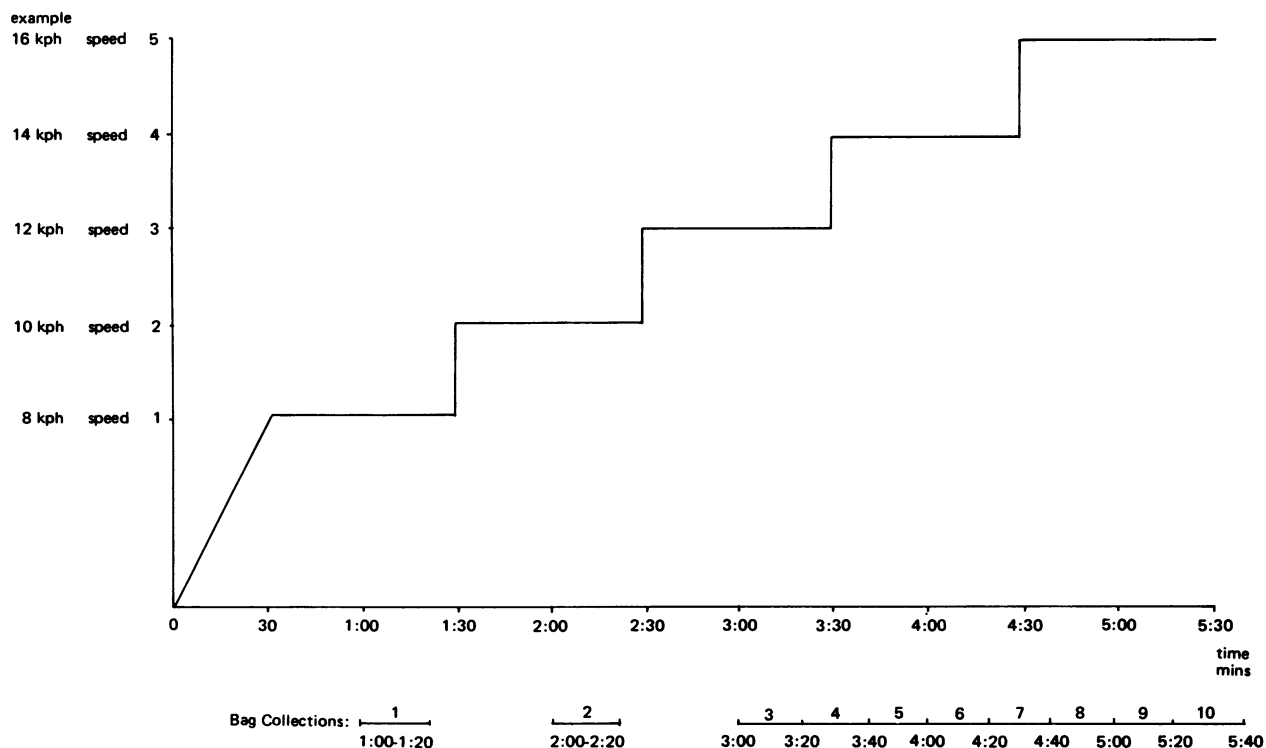
Fig. 1. The pneumotachograph transducer is on the inspiratory side. The expiratory side goes to a Douglas bag via the changing junction. The safety harness activates a cut-out in the event of a fall. Position of ECG leads — running: sternal angle and left at the 9th intercostal space, in mid-clavicular line (earth on right ribs).

they reached a mean of 53%. The swimmers reached 72% to 85%, with a mean of 79%. The figures differ at the 0.001 level of significance.

The heart rates were much closer, runners attaining 91% to 103% of their running rate by pulling, mean 95%; similarly the swimmers attained 93% to 98%, mean 96%.

Oxygen pulse, the volume of oxygen consumed per heart beat, is where the most clear-cut difference between the groups is seen. In running, the O_2 pulse max was 23 ml/beat for the runners and 24 for the swimmers, while in pulling the runners dropped to 13 and the swimmers to 20, the difference between the groups being significant at the 0.01 level for pulling, but the same for running.

These results (Fig. 7) show a negative correlation $r = 0.68$, $p < 0.05$. This may be due to a number of



All subjects stopped between 3:25 and 5:25

Fig. 2.

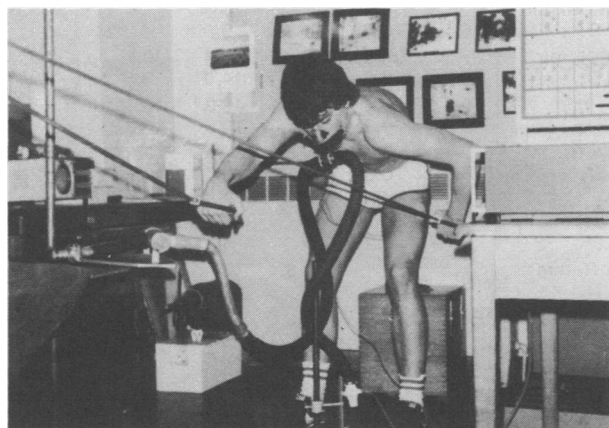


Fig. 3. Shock cords are pulled alternating right arm-left arm from arms length to outside of the thigh at a rate set by a metronome.

Note ECG connection on left thigh and sternal angle (earth on right ribs) and pneumotachograph transducer on inspiratory side.

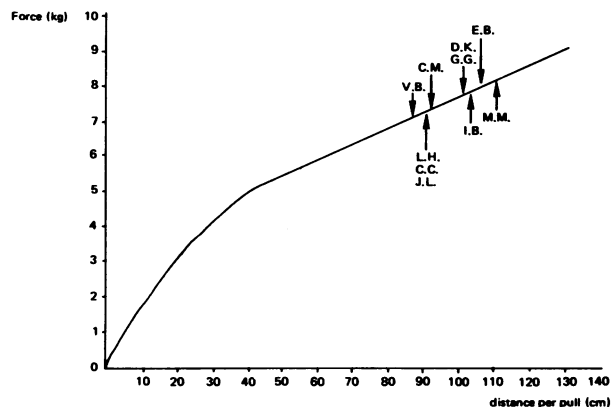


Fig. 4. Length-tension curve for shock cords.

points, but the main contributing factor is the biased nature of the groups, swimmers having been trained with arm work predominating, whereas running is a leg dominated activity. While VO_2 max measured using any standard ergometer may indicate general MAP in untrained or non-specifically trained subjects, performance in one test should not be correlated with another in

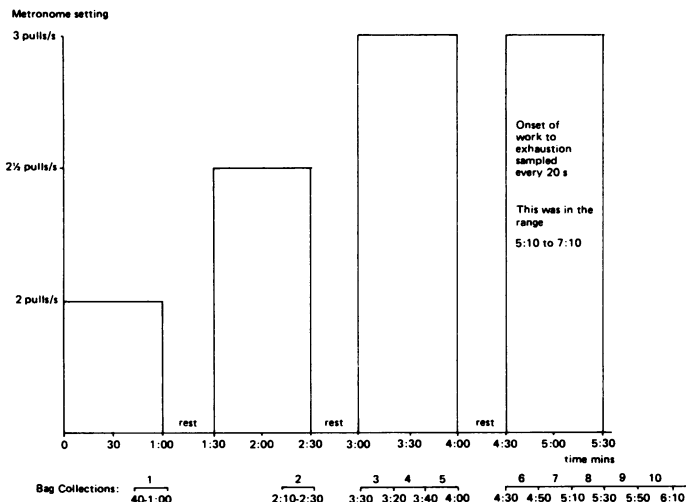


Fig. 5. Pulling ergometry.

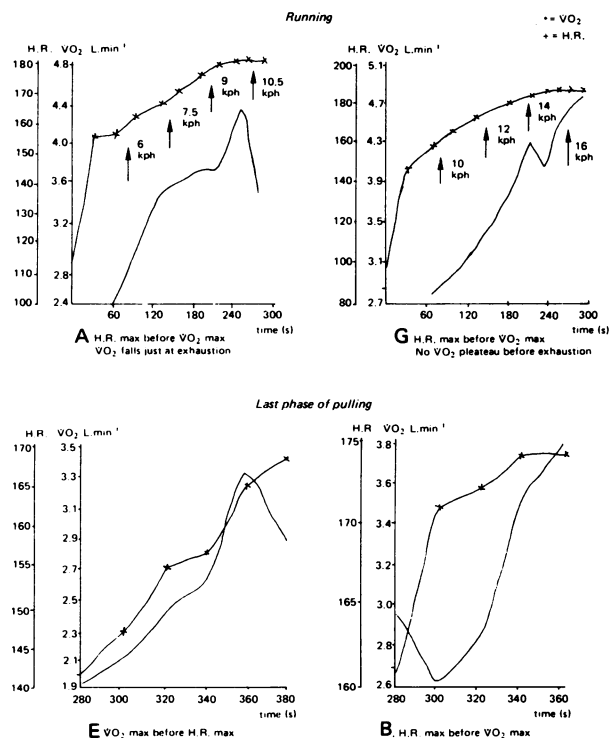


Fig. 6

those athletes specifically trained to do either. This confirms the view that for such athletes one is not justified in generalising from one VO_2 max value to a theoretical whole body MAP (Bouchard et al, 1979).

TABLE II

	Table of mean values					
	running			pulling		
	runners	swimmers	significance	runners	swimmers	significance
$\text{VO}_2 \text{ L.min}^{-1}$	4.15	4.5	N.S.	2.2	3.5	$p < 0.01$
S.D.	0.53	0.6		0.5	0.3	
$\text{VO}_2 \text{ ml.kg}^{-1} \text{ min}^{-1}$	70.24	59.98	$p < 0.01$	37.4	47.1	$p < 0.02$
S.D.	3.27	5.65		6.5	2.2	
$\text{VO}_2 \text{ ml.kg}^{-1} \text{ LBM min}^{-1}$	80.9	72.3	$p < 0.05$	42.74	56.93	$p < 0.01$
S.D.	6.1	4.42		5.6	4.2	
$\text{V}_E \text{ L.min}^{-1}$	107.5	106.5	N.S.	67.4	89.2	$p < 0.02$
S.D.	14.9	5.5		14.0	9.0	
$\text{V}_f \text{ min}^{-1}$	50.4	43.4	N.S.	49.3	40.1	N.S.
S.D.	9.3	9.5		18.8	6.7	
T.V.L	2.2	2.5	N.S.	1.45	2.28	$p < 0.02$
S.D.	0.6	0.5		0.3	0.5	
$\text{V}_{eq} \text{ L(100 ml)} \text{ O}_2^{-1}$	2.4	2.6	N.S.	3.1	2.6	$p < 0.05$
S.D.	0.29	0.25		0.3	0.36	
H.R. min^{-1}	181	186	N.S.	172	179	N.S.
S.D.	6	6		12	7	
$\text{O}_2 \text{ pulse ml.beat}^{-1}$	22.9	23.9	N.S.	12.9	19.6	$p < 0.01$
S.D.	2.4	3.1		2.6	1.7	

However, the value of more specific quantification of VO_2 max for a certain exercise has been shown, and although not enough swimmers who swim the same events have been tested to find a correlation between VO_2 max pulling and swimming performance, the test could be used longitudinally to monitor change in swimming fitness with time as it is evident that swimming training does cause major adaptation in favour of this

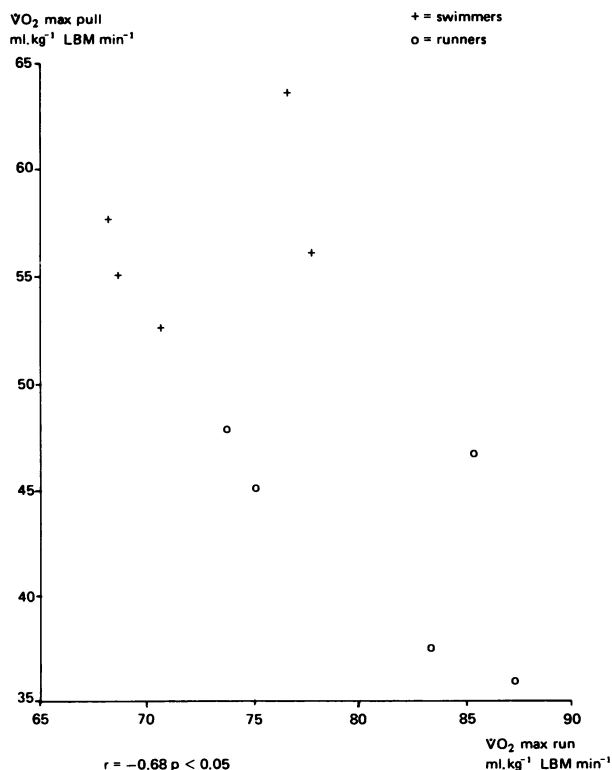


Fig. 7. VO_2 max pull against VO_2 max run.

type of work. Those who say that swimmers' VO_2 max should not be specified for body weight since they do not carry their body weight swimming (Armstrong

and Davies, 1981; Faulkner, 1968; Holmer, 1974; Holmer et al, 1974), fail to separate a large VO_2 max due to large size from a large VO_2 max due to efficient adaptation. The favoured expression in this study is $ml.kg^{-1} (LBM)min^{-1}$ since it most nearly quantifies the O_2 -consuming mass, although mass of active tissue, rather than LBM would be even better (Buskirk and Taylor, 1957).

CONCLUDING REMARKS

While pulling ergometry is not suitable for measuring absolute VO_2 max, it may be a more meaningful test for swimmers whose training involves mostly upper body conditioning, and for whom any leg training is done in a manner quite different from running or cycling. Thus VO_2 max pulling with the pulling exercise specified could be used longitudinally to study the effects of a training programme and possibly for prediction of likely swimming performance.

Achievements by swimmers on the pulling test bore no relationship to their running VO_2 max, nor did the runners show correlation between their running and pulling.

For any sport, the ergometry should be closely related to the training and less emphasis be placed on absolute VO_2 max than the VO_2 max attained for a specific test relevant to the sport in question.

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